Gesture-Based Control of TurtleBot 4 Using ROS 2 Humble

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***Abstract*—This project explores gesture-based control of the TurtleBot 4 using ROS 2 Humble. By integrating MediaPipe's gesture recognition framework with ROS 2's motion command capabilities, we enable intuitive, touch-free interaction with the robot. The system processes real-time camera feed to detect hand gestures, which are mapped to corresponding movement commands such as forward, stop, turn left, and turn right. The implementation demonstrates effective control under controlled environmental conditions, with potential applications in assistive technologies, robotics education, and human-robot interaction. Future work could include improving robustness and expanding gesture vocabulary.**

***Index Terms*—gesture recognition, ROS 2, TurtleBot, MediaPipe**

I. Introduction

A. Background

Gesture recognition is a technique where hand or body movements are interpreted as inputs for human-computer interaction. It has found applications in various domains, such as gaming, virtual reality, assistive robotics, and healthcare.

B. Motivation

Gestures are a natural and intuitive form of communication for humans, often used in situations where verbal communication is limited or impractical. Examples include manual traffic signaling by police officers, sign language used by the hearing-impaired, and hand signals in aviation and construction for guiding operations. Extending this natural communication method to robots enhances human-robot interaction, offering touch-free control and making the system accessible and user-friendly. Gesture-based control can be particularly useful in dynamic or hazardous environments where traditional input methods, such as joysticks or keyboards, may not be feasible.

C. Literature Review

The field of human-robot interaction has witnessed significant advancements in gesture recognition technologies, presenting innovative approaches to intuitive machine control. Recent studies, such as [1], provide a comprehensive examination of gesture-based teleoperation, highlighting the critical role of sophisticated recognition methodologies in modern robotics.

1) Technological Foundations: Contemporary gesture recognition systems leverage advanced computer vision and machine learning techniques. In [2], researchers meticulously analyzed the landscape of hand gesture recognition, identifying key technological challenges and emerging solutions. Their findings underscore the complexity of translating human gestural communication into precise robotic commands.

MediaPipe, developed by Google researchers, represents a pivotal breakthrough in real-time perception technologies. For instance, [3] demonstrated the framework's capability to process complex visual inputs with minimal latency, making it particularly suited for interactive robotic applications. MediaPipe's ability to track and interpret hand landmarks in real-time addresses critical challenges in gesture-based control systems.

2) Architectural Considerations in Robotic Control: The Robot Operating System (ROS) 2 has emerged as a fundamental architecture for modern robotic systems. The work in [4] comprehensively explored ROS 2's design, emphasizing its enhanced communication protocols and modular structure. This architectural advancement provides a robust foundation for implementing sophisticated human-robot interaction mechanisms.

3) Emerging Research Trajectories: Research in [5] identified gesture-based robotic control as a transformative paradigm in human-robot interaction. Their study highlighted the potential for more intuitive and accessible robotic interfaces, particularly in applications ranging from assistive technologies to complex industrial environments.

4) Research Implications: The convergence of advanced gesture recognition technologies, sophisticated machine learning algorithms, and robust robotic communication frameworks presents several critical insights:

- Gesture recognition is transitioning from experimental to practical implementation.
- Real-time processing capabilities are becoming increasingly sophisticated.
- Interdisciplinary approaches are crucial for advancing human-robot interaction technologies.

D. Project Objectives

This project aims to implement gesture-based control for the TurtleBot 4 using ROS 2. The system processes a live camera feed to detect hand gestures and translate them into motion commands such as moving forward, turning, or stopping.

II. Problem Formulation

A. Objective

The primary objective of this research is to develop an innovative gesture-based control system for the TurtleBot 4, utilizing advanced computer vision and robotic communication technologies. By integrating real-time video processing with sophisticated gesture recognition algorithms, the system aims to create an intuitive and accessible human-robot interaction method.

B. Inputs and Outputs

The system leverages a comprehensive input methodology, utilizing a real-time video stream captured through a camera and processed using MediaPipe's advanced pre-trained hand gesture recognition models. This input is systematically translated into precise motion commands sent to the TurtleBot 4 via the ROS 2 '/cmd_vel' communication topic.

The motion control repertoire includes four distinct gesture-based commands: an open palm or neutral gesture to halt the robot, a closed fist to initiate forward movement, an upward-pointing gesture to execute a left turn, and a victory hand signal to command a right turn. This carefully designed command set provides a balanced and intuitive control interface.

C. Constraints and Operational Parameters

The research acknowledges several critical operational constraints that define the system's performance envelope. The gesture recognition system requires an unobstructed camera view, ensuring clear and consistent hand tracking. Optimal performance is predicated on controlled indoor environments with consistent lighting conditions.

The system's design emphasizes gesture distinctiveness and minimal latency, with a focus on creating a responsive and reliable human-robot interaction mechanism. These carefully considered parameters establish the foundational requirements for effective gesture-based robotic control.

III. Methodology

A. System Architecture Overview

The proposed gesture-based robotic control system integrates three critical technological components into a cohesive and sophisticated interaction framework. The gesture recognition module, powered by MediaPipe's advanced computer vision algorithms, serves as the primary input processor. This module seamlessly interfaces with a mapping component that translates detected gestures into standardized robotic motion commands, which are then transmitted through the ROS 2 control module.

B. System Architecture

The data flow architecture represents a carefully engineered pipeline, beginning with raw camera input and culminating in precise robotic motion. Each computational stage is designed to minimize latency and maximize gesture interpretation accuracy, ensuring a responsive and intuitive user experience.

Fig. 1 shows the system architecture.

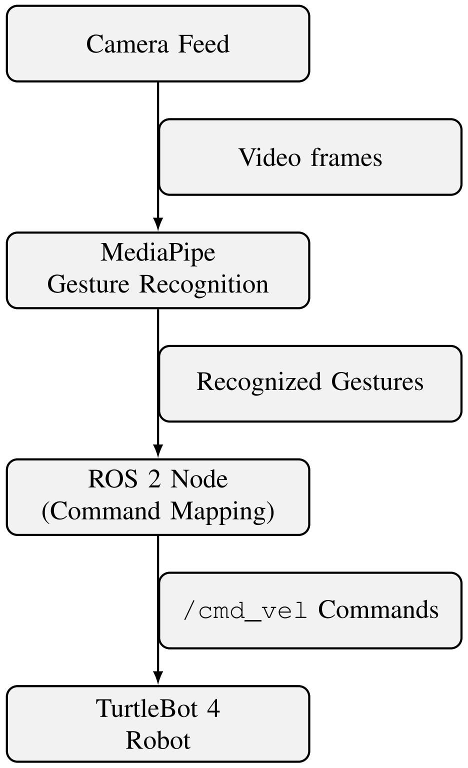

Fig. 1. Overview of the System Architecture.

C. Gesture Recognition Methodology

MediaPipe's pre-trained gesture recognition models represent the cornerstone of the system's perceptual capabilities. These sophisticated machine learning models enable real-time hand landmark tracking and gesture classification with remarkable precision. By processing live camera feeds, the system can instantaneously detect and interpret complex hand configurations, transforming human gestural communication into actionable robotic commands.

D. ROS 2 Integration Strategy

The Robot Operating System 2 (ROS 2) provides a robust communication infrastructure for translating recognized gestures into motion commands. Utilizing Python's 'rclpy' library, a dedicated ROS 2 node subscribes to gesture recognition outputs and publishes corresponding velocity commands to the TurtleBot 4's '/cmd_vel' topic. This integration ensures a standardized and flexible approach to robotic control, leveraging ROS 2's modular and extensible architectural design.

E. Tools and Technologies Used

1) **MediaPipe**: Gesture recognition and landmark tracking.
2) **ROS 2 Humble**: Framework for robot control and communication.
3) **OpenCV**: Processing and displaying the live video feed.
4) **Hardware**: TurtleBot 4, camera, and a laptop running ROS 2.
5) **Languages**: Python for implementing nodes and scripts.

IV. Implementation Details

A. Gesture-to-Command Mapping

The gestures recognized by MediaPipe are mapped to specific motion commands. The mapping is as follows:

1) **Open Palm / None**: Stop the TurtleBot.
2) **Closed Fist**: Move forward.
3) **Pointing Up**: Turn left.
4) **Victory**: Turn right.

B. Processing Pipeline

1) The system processes a live camera feed and identifies gestures using MediaPipe's models.
2) Recognized gestures are passed to a ROS 2 node, which translates them into motion commands.
3) Motion commands are published to the TurtleBot 4's '/cmd_vel' topic.

C. Command Examples

Below is a curated excerpt from the gesture recognition and control script, focusing on the key logic that maps recognized gestures to TurtleBot commands.

```
if gesture_label == "open_palm" or
gesture_label == "none":
    gesture_control_node.stop()
elif gesture_label == "closed_fist":
    gesture_control_node.move_forward()
elif gesture_label == "pointing_up":
    gesture_control_node.turn_left()
elif gesture_label == "victory":
    gesture_control_node.turn_right()
```

D. Key Algorithms and Functions

1) **Gesture Recognition**: Utilizes MediaPipe's pre-trained gesture recognition models for real-time gesture classification.
2) **ROS 2 Node**: Implements a Python-based ROS 2 node using the 'rclpy' library to send velocity commands.
3) **Command Publishing**: Motion commands are published as geometry_msgs/Twist messages for linear and angular velocity control.

V. Results

A. System Performance

The system successfully recognized gestures and translated them into motion commands in real-time. Latency between gesture recognition and robot motion was minimal, ensuring smooth control.

B. Testing and Validation Methods

The system was evaluated through practical usability tests, involving multiple users with varying levels of familiarity with gesture controls. Each user performed a set of predefined gestures (open palm, closed fist, pointing up, and victory) to control the TurtleBot's movements.

During these trials, the system exhibited minimal and imperceptible latency, with instantaneous robot responses to recognized gestures. The gesture recognition accuracy remained consistently high under controlled indoor lighting conditions, and no misclassifications were observed. Users reported that the interface felt intuitive and responsive, confirming the system's effectiveness and reliability.

C. Challenges and Limitations

The accuracy of gesture recognition was affected under poor or variable lighting, also, some gestures were occasionally misclassified when performed quickly or outside the camera's focal point. The system is currently limited to a predefined set of four gestures. The system operates effectively only in controlled indoor environments with sufficient lighting.

VI. Conclusion and Future Work

A. Conclusion

This project successfully implemented gesture-based control for the TurtleBot 4 using ROS 2 Humble. The system demonstrated real-time responsiveness, effectively translating recognized gestures into motion commands. The use of gestures as an interaction method proved intuitive and accessible, highlighting potential applications in robotics applications, assistive technology, and human-robot interaction. The project demonstrated the feasibility of gesture-based control for robots, offering an intuitive and touch-free interaction method. Improvements in gesture detection robustness and additional gesture vocabulary could significantly enhance usability.

B. Future Work

1) **Expand Gesture Vocabulary**: Introduce additional gestures for more complex robot behaviors, such as backward motion or predefined routes.
2) **Enhance Robustness**: Improve the system's resilience to variations in lighting and environmental conditions.
3) **Integrate Multimodal Interaction**: Combine gesture control with other input methods, such as voice commands, for a more versatile control system.
4) **Deploy in Dynamic Environments**: Adapt the system to work reliably in outdoor or dynamic settings with variable lighting and background conditions.

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